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## ARTICLE XXI.

*On the Causes of the Tornado, or Water Spout. By R. Hare, M. D., &c., &c., &c.*

IN July last, I visited the scene of the tornado, which had in the previous month produced so much damage in and near New Brunswick, New Jersey, and heard it described by various witnesses, and have likewise been edified by the observations made respecting its effects by professors Henry, Torrey, Johnson and other sagacious and learned observers, and especially those of my friends, professor A. D. Bache, and Mr Espy. Probably in no other instance have the effects of a tornado been so faithfully and skilfully traced, ascertained and registered. Professor Bache regularly surveyed the path of the devastating agent, and ascertained the bearings of the various bodies prostrated by it, so as to make several accurate plots.\* From an examination of these, the proximate causes of the changes effected, are those of a vertical current at the centre or axis of the tornado, and of a horizontal conflux of the air towards that axis from the surrounding space. Some trees appear to have been thrown down on the approach of the hiatus, both directly in front of it and on either side; some fell at right angles, others obliquely to the path. Hence they were found to have a great variety of bearings, but always pointing towards the path.

\* I hope that these plots will appear in this volume.

The time of their falling, and consequently the direction agreeably to the observations of professor Bache, appear to have been determined not only by the extent of the force to which they were exposed, but likewise by the strength of their roots, or the degree of protection afforded them by other bodies, trees or houses for instance. On these accounts, neighbouring trees, falling at different times, had different bearings ; but that they all fell towards the point occupied by the axis of the tornado at the time of their overthrow, appears to be consistent with the facts. In one instance, both professor Bache and Mr Espy observed that the post of a frame building, being dislodged from the stone on which it rested, was first moved towards the path of the tornado in one direction about eighteen inches, marking its course by a furrow in the ground, and afterwards moved in another direction, nearly at right angles to the former, leaving a similar indication of the course in which it had moved. Intermediately between the time when the tornado bore in those directions, the frame was protected by a house.

While the phenomena above described sufficiently indicate the existence of a horizontal conflux of the air, that of a vertical force was demonstrated by the transportation of the debris of the houses and trees, as well as lighter bodies, to a great distance. A lady's reticule was carried seven miles from New Brunswick, and a letter twenty miles. The piece of timber, technically called the plate, on which the rafters of the roof of a meetinghouse in New Brunswick rested, was carried nearly a quarter of a mile, and lodged in some trees beyond the Raritan. The fields, on the otherside of that river, were strewn with shingles torn from the houses in the town.

After maturely considering all the facts, I am led to suggest that a tornado is the effect of an electrified current of air, superseding the more usual means of discharge between the earth and clouds in those sparks or flashes which are called lightning. I conceive that the inevitable effect of such a current would be to counteract within its sphere the pressure of the atmosphere, and thus enable this fluid, in obedience to its elasticity, to rush into the rarer medium above.

It will, I believe, be admitted, that whenever there is sufficient electricity generated to afford a succession of sparks, the quantity must be sufficient, under favourable circumstances, to be productive of an

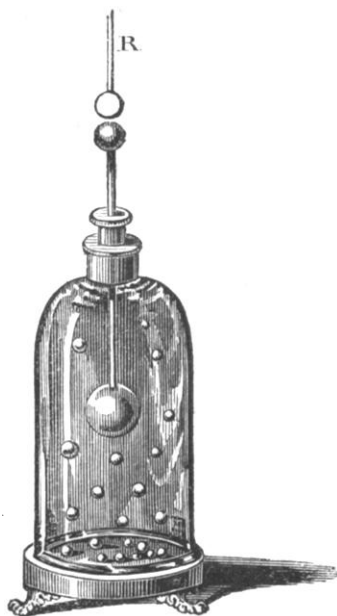
electrical current; and that light bodies, lying upon one of the electrified surfaces, may be attracted more or less by the other.

The phenomena of the rise and fall of electrified pith balls, called electrical hail, sufficiently justify this last mentioned statement; while the continuous stream is illustrated by the electrical brush, or the blast of air produced by a highly electrified point.

It will also be conceded, that thunder and lightning are caused by discharges of electricity between the earth and clouds, analogous to those of a Leyden jar or pane; the air performing the part of an electric in place of the glass, while the cloud acts as a coating.

It follows that the phenomena above mentioned as liable to arise between oppositely electrified bodies, may be expected to take place between the clouds and the earth, with effects as much exceeding those produced by human agency, as the snap and spark of an electric battery are exceeded by thunder and lightning. If in the one case pith balls and other light bodies are lifted; in the other, water, trees, houses, haystacks and barns may be powerfully affected.\* If from a point electrified by a human contrivance, a blast of air is induced; it is as-

\* This figure affords an illustration in miniature of the rise and fall of bodies situated between oppositely electrified surfaces, which, in the gigantic operations of nature, are conceived to be the exciting cause of the tornado. The phenomena represented by it are designated in Pixii's catalogue as "*grelé électrique*," and may be thus explained. A metallic rod supports one ball within the bell glass, another without, so as to be in contact with the knob of another rod R, proceeding from the conductor of an electrical machine in operation. The brass ball being by these means intensely electrified, attracts some of the pith balls which lie upon the metallic dish in which the bell is situated, and which should communicate with the cushions of the machine. As soon as the pith balls come into contact with the electrified ball, becoming similarly excited, agreeably to the general law they recede from each other and are attracted by the oppositely electrified dish. Reaching the dish, they attain the same electrical state as at first, and are, of course, liable to be attracted again.



surely not unreasonable to ascribe to the analogous electrical apparatus of nature, aided by the elasticity of the air, a vertical hurricane. It was under the well founded impression that lightning may be superseded by a current, that we have been instructed by Franklin, to surmount our lightning rods by metallic points, by which electrical discharges from thunder clouds are expected to be conveyed to the earth gradually, which might otherwise pass in sparks of lightning of a formidable magnitude.

If, then, it be demonstrated that a continuous discharge of electricity may become the substitute for lightning, and that within the sphere of the discharge the air may be so lifted as to counteract its gravity; it is in the next place only necessary to advert to facts perfectly well known, in order to point out a cause of acceleration sufficient to account for the well known violence of the tornado.

At the height of fifteen miles, the air has been ascertained to have less than one-thirtieth of the density of the stratum next the earth. Of course this substratum would exercise a force nearly equal to the atmospheric pressure, or about fourteen and a half pounds to the square inch, in order to attain the space occupied by the rare medium, to which allusion has been made. It follows that if the weight of the superincumbent air were removed or counteracted, that the inferior stratum would rise with explosive violence.

While the air is thus carried upwards by the concurrent influence of electrical attraction, and the reaction of its own previously constrained elasticity; other bodies are lifted, both by electrical attraction, and the blast of air to which it gives rise. Hence houses within the sphere of the excitement are burst by the expansion of the air which they contain, their walls being thrown outwards, and their roofs carried away; while, by the afflux of the atmosphere requisite to the restoration of its equilibrium, trees, houses and other bodies are thrown inwards towards the vertical current, from before, as well as from either side.

When once a vertical current is established, and a vortex produced, I conceive that it may continue after the exciting cause may have ceased to act. The effect of a vortex in protecting the space

about which it is formed, from the pressure of the fluid in which it has been induced, must be familiar to every observer. In fact, Franklin ascribed the water spout to a whirlwind produced by the concurrence of the atmosphere to a given point. His hypothesis was, as I conceive, unsatisfactory, because it did not assign any adequate cause for the concentration of the wind, or for the hiatus which was presumed to be the cause. This deficiency is supplied, if my suggestions be correct.

One fact, of which I am myself a witness, cannot be explained without supposing a gyratory force. About six feet of a brick chimney, without being thrown down, were so twisted on the remaining inferior portion as to be left with its corners projecting.

I have hardly deemed it necessary to advert to the cause of the progressive motion of a tornado, since that would appear evidently due to the current of the atmosphere within which it may be created.

I believe that the electrical excitement which gives rise to atmospheric discharges of electricity, in whatever form they may occur, is usually ascribed to the chemical changes taking place in the atmosphere; especially the formation or condensation of vapour.

Another view of this subject has suggested itself to my mind. It is known that the atmosphere acts generally as an electric, while the earth acts as a conductor of electricity; and since the electric fluid passes through an exhausted receiver with great facility, it results that the rare medium which exists at a great elevation, is equivalent to another conductor. Hence it is evident that there are three enormous concentric spaces, of which that which is intermediate contains an electric, to which the others may act as coatings. When the tendency of electric fluid to preserve an equilibrium is taken into view, I believe myself justified in the inference, that not only the space occupied by the globe, but the region beyond our atmosphere, or where the air is sufficiently rare to act as a conductor, must abound with electricity. Thus the atmosphere is situated between two oceans of electricity, of which the tension may often be different. Between these electric oceans, the clouds, floating in the non-conducting air, must act as movable insulated conductors; and from the excitement consequent upon induction, chemical changes, or their proximity to the celestial electric ocean, must be liable to be

electrified differently from each other, and from the terrestrial electric ocean.

The phenomena of thunder storms may arise, from the passage of electricity from one electric ocean to the other being facilitated by an intervening accumulation of the clouds, or in consequence of discharges from one insulated congeries of clouds to another through the earth.

The aurora borealis may arise from discharges from one ocean to the other of electricity, which, not being concentrated by its attraction for intervening clouds within air sufficiently dense to act as an electric, assumes the diffuse form which characterizes that phenomenon.

Falling stars may consist of electric matter, in transitu between one portion of the celestial electric ocean and another, tending to restore the equilibrium when disturbed. They may, in fact, consist of electric matter, passing from one mass of moisture to another; as it may be imagined that in an expanse so vast, in which the tension is so low, there may be a great diversity as respects the quantity of moisture existing in different parts. Indeed, it may be conceived that at times the clouds, insulated from each other, may make their reciprocal discharges through the region occupied by the celestial ocean.

I have been informed by my intelligent friend, Mr Quinby, who resided for some time in Peru, at an elevation of fifteen thousand feet above the level of the ocean, that the clouds in that elevated region are far more electric than in the lower country of the same latitude; and that, on this account, it was considered as dangerous, at times, to travel in the "*sicrras*," or table land. Possibly thunder storms are more frequent in warm weather, in consequence of the greater elevation which the clouds then attain, and their consequent approximation to the celestial ocean of electricity.

Consistently with the hypothesis which I suggested in my essay on the gales of the United States, the enduring rains which accompany those gales are attributed to the contact of an upper warm and moist current of air, with a lower current of the same fluid at an inferior temperature, and moving in an opposite direction. It would follow that, on such occasions, the electricity of the upper region would be diffused among the clouds within the upper stratum, without reaching

those existing within the lower current. But in such cases neither stratum would be sufficiently insulated and restricted in its extent to transmit the electricity in a concentrated form, or to be liable to the intense excitement necessary to produce a tornado or lightning.

FACTS AND OBSERVATIONS RESPECTING THE TORNADO WHICH OCCURRED AT NEW BRUNSWICK, NEW JERSEY, IN JUNE LAST, ABSTRACTED FROM A WRITTEN STATEMENT MADE BY JAMES P. ESPY, M. A. P. S.

*By the Author of the preceding Article.*

THE tornado was formed about seven and a half miles west of New Brunswick, and, moving at the rate of about twenty-five or thirty miles in an hour, terminated suddenly at Amboy, about seventeen and a half miles from the place of its commencement. It appeared like an inverted cone, of which the base was in the clouds, and the vertex upon the earth. It prostrated or carried off every movable body within its path; which was from two hundred to four hundred yards wide. Trees which were embraced successively within its axis were thrown down in a direction parallel to its path; those on either side always pointing towards some point which had been under its axis. Houses were unroofed, and, in some instances, unfloored; in others, their walls were thrown down outwards, as if burst by an explosion. There are two facts stated by Mr Espy, and confirmed by professor Bache, which demonstrate fully the existence of an hiatus. In a house which was exposed to the vertical influence of the tornado, a sheet was lifted from a bed, and carried into a fissure made in the southern wall, which subsequently closed and retained it. The same result was observed in the case of a handkerchief, similarly fastened into a fissure in the northern wall. In some instances, frame buildings were lifted entire from their foundations. Joists and rafters were torn from a house and thrown down at the distance from it of about four hundred yards, and in a direction opposite to that in which the trees not lifted from the earth's surface were prostrated. Of course lighter bodies, such as shingles, hats, books and papers, and branches and leaves of trees, were carried



to much greater distances. There was no general rain, but hail and rain accompanied the fall of the other bodies. The tornado lasted, in any one place, for but a few seconds: the whole of the damage done at a farm having been accomplished, as the farmer stated, while he was passing from the front to the rear of his mansion, so that, by the time that he reached the back door, there was a perfect calm. Meanwhile, his house and barn were unroofed, and all the neighbouring trees thrown down. The noise which accompanied the phenomenon was by every witness described as terrific, being best exemplified by the rumbling of an immense number of heavy carriages. Every object in its path was bespattered with mud on the side towards that from which it advanced. Houses looked as if roughcast, and individuals were so covered with dirt as to be disguised.

Some thunder and lightning attended the tornado. Some trees, which resisted the onset, yielded subsequently; and hence were piled upon those which had fallen earlier. The weaker trees were undermost, and pointed in the direction in which the tornado approached; while the stronger were on the top, pointing in the direction in which it moved away.

Four different places were noticed, where all the trees lay, with their summits directed to a common centre. In the middle of one of these localities, the house was unroofed, and the handkerchief and sheet were lodged within the fissures in the walls, as already stated. The windows in the same house were all broken, and much of the glass thrown outside. From the evidence, Mr Espy infers that the apparent height of the tornado was about a mile. He states that there were, on the same day, two other tornadoes about seventeen miles apart; and of which the nearest was about the same distance from that of New Brunswick. He conceives that the phenomena all concurred to demonstrate an "inward motion from all directions towards the centre of the tornado, and an upward motion in the middle." These statements of Mr Espy are confirmed by professor Bache.

One fact of some importance has not been mentioned by Mr Espy, which was observed by persons who were upon the ground during, or soon after the catastrophe. I allude to the partial withering of the foliage of those small trees or shrubs, which, from their suppleness,

were like the reed in the fable, neither uprooted nor overthrown. This unpleasant effect was perceptible when I visited the scene. Each leaf was only partially withered. As it would be inconceivable that mechanical laceration could have thus extended itself equably among the foliage, a surmise may be warranted that the change was effected by the electricity associated with the tornado.

*Concluding Remarks by the Author of the Article.*

I ought, perhaps, sooner to have acknowledged that I am aware that it has often been suggested that water spouts might be caused by electricity; but the conjecture has not, as far as my information goes, been heretofore supported by any satisfactory explanation as to the mode in which such a tremendous power could arise from that source. That I am warranted in this impression, will, I trust, appear evident from the circumstance that two of the most distinguished among the late writers in the department of science to which the subject belongs, seem to admit, or to demonstrate, their inability to afford any explanation. I allude to Pouillet, and Despretz.

In his treatise on meteorology, Pouillet introduces two narratives respecting tornadoes, which were analogous in every essential point to that of New Brunswick. Especially the existence of an hiatus is proved by the allegation that the walls of prostrated houses were thrown down outwards. A labourer was first urged forwards, in the next place lifted, and lastly overthrown.

The learned and ingenious author concludes with these remarks.

“Comment cette puissance, quelquefois si prodigieuse, peut-elle prendre naissance au milieu des airs? C’est une question, il faut de dire, à laquelle la science ne peut faire aucune réponse précise. De toutes les conjectures vagues et hasardées, que l’on peut faire sur l’origine de ce météore, la moins invraisemblable est peut-être celle que le regarde comme un tourbillon d’une excessive intensité. Mais une discussion sur ce point nous semblerait prématurée; il faut multiplier les observations, et constater avec plus de précision toutes les circonstances de ces phénomènes.”—*Elemens de Physique Experimentale et de Météorologie*, vol. 2, p. 727.

All the information respecting tornadoes afforded by Despretz is comprised in the following paragraphs, which I quote in his own words.

“*Trombe.* La trombe se montre en mer et sur la terre; tantôt elle semble sortir du sein de la mer, et s’élève jusqu’aux nuages; tantôt elle descend des nuages jusqu’à terre.

“C’est une colonne d’eau cônica qui tourne sur elle-même avec une grande vitesse; elle a quelquefois jusqu’à plus de deux cents mètres de base. Elle est très-commune entre les tropiques: les navigateurs passent rarement près des côtes de Guinée sans en apercevoir plusieurs.

“Les trombes produisent des effets terribles; elles déracinent les arbres, renversent les faibles habitations, soulèvent les voitures, etc.

“On peut se faire une idée des trombes par les tourbillons de poussière qui se forment tout à-coup, en été, sur les routes, et qui tournent sur eux-mêmes avec une grande rapidité.”—*Traité Elementaire de Physique, paragraph 656, page 828, par C. Despretz.*

In Nicholson’s *Journal*, quarto series, London 1797, vol. 1, page 583, there is an interesting account of some tornadoes seen from Nice, illustrated by engravings, by M. Michaud, who appears to consider them as the effect of electricity, and infers that he could produce the phenomenon in miniature by the aid of a machine, as thunder and lightning are by the same means illustrated. This I have found to be erroneous, as far as my experience goes, and from a cause which is, agreeably to my hypothesis, quite evident. I mean the absence of the co-operating influence of the air when emancipated by electric attraction from the confinement arising from its own weight.

The theoretic remarks of Michaud are very brief, and, to me, scarcely intelligible, as he does not inform us in what way he supposes the electric fluid to operate.

I have understood, since I conceived my hypothesis, that Beccaria ascribed water spouts to electricity, but I have not had the advantage of learning by what reasoning he justified his inferences. However, should it appear that I have made, through the want of information, any undue claim to priority, I shall cheerfully do justice to any philosopher whose speculations I may have overlooked.